Vol. 25, No. 1, pp. 115-119 (2025)
Journal of Agricultural Physics
ISSN 0973-032X
https://doi.org/10.56093/JAP.v25i1.12

SHORT COMMUNICATION

Dynamics of Available-K under Biochar Applied Alfisol Soil

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ABSTRACT

Rice straw biochar is a promising amendment for improving nutrient availability and soil health in acidic, nutrient-depleted Alfisols of eastern India. This study assessed the effect on the dynamics of soil potassium (K) and wheat yield under alfisol of Jharkhand. A field experiment was conducted using five (0, 2.5, 5, 10 and 12.5 t ha^{-1}) biochar doses (B0, B2.5, B5, B10, and B12.5) with the recommended dose of NPK (100:50:20 kg ha^{-1}). Soil sampling at 7, 37, 66, and 121 days after basal fertilizer application showed that biochar significantly increased available soil K ($p < 0.01$) at all stages, with higher doses maintaining greater K levels throughout crop growth. Enhanced K availability was attributed to the biochar's intrinsic K content. The total and available K contents in the biochar were 18 g kg^{-1} and 6460 mg kg^{-1}, respectively. The study indicates that the application of rice straw biochar can effectively improve soil K availability in acidic Alfisols.

Key words: Rice straw biochar, Wheat, Alfisols, Potassium availability, Nitrogen fertilization, Soil fertility

Introduction

The Alfisol soil restricts nutrient availability, particularly K, and shows poor fertiliser-use efficiency under rainfed conditions. Low pH, limited microbial biomass, and moisture variability further reduce nutrient uptake and crop performance (Ghosh *et al*., 2019). The majority of the soil in Jharkhand, especially in the Hazaribagh district, is acidic, with low nutrient availability (Gupta *et al*., 2020). Potassium (K) is an essential plant nutrient that plays an essential role in plant growth and drought tolerance. However, it has been reported that soil K availability is lower in acidic soils than in other soil types (Zhang *et al*., 2009). Biochar, a carbon-rich product of biomass pyrolysis, has emerged as a promising amendment for acidic and degraded soils due to its high surface area, porosity, and ability to enhance soil structure, nutrient retention, and microbial activity (Agegnehu *et al*., 2017). Potassium fixation in acidic Alfisols arises primarily from specific mineralogical interactions. Interlayer sites of clay minerals such as illite, vermiculite, and hydroxy-interlayered vermiculite trap K^+ ions, particularly under low-pH and fluctuating soil-moisture conditions. In acidic environments, hydroxy-Al polymers form in clay interlayers, reducing interlayer spacing and enhancing electrostatic attraction for K^+, thus promoting its transformation into non-exchangeable forms (Havlin *et al*., 2014). This fixation is further exacerbated during drying cycles, where the collapse of interlayer

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spaces tightly binds K^+, making it unavailable during subsequent crop demand (Sparks & Huang, 1985). As a result, even when fertilizer K is applied, a considerable fraction becomes held in lattice positions, contributing to chronic K deficiency in wheat-growing Alfisols of the region. Biochar often contains substantial quantities of soluble and exchangeable K in its ash fraction, depending on feedstock and pyrolysis conditions (Yuan *et al.*, 2011). These K forms are readily released into the soil solution through leaching and ion exchange, providing an immediate supply to plants. Equally important are the soil-modifying properties of biochar. The alkaline nature of biochar raises soil pH, enhances cation exchange capacity (CEC), and improves soil aggregation, collectively reducing the tendency of K^+ to become fixed in interlayer sites (Lehmann & Joseph, 2015). By increasing CEC and altering surface charge characteristics of biochar it is possible to shift K from non-exchangeable to exchangeable pools, thus improving both short-term and long-term K availability (Gundale & DeLuca, 2006). Moreover, biochar's porous structure facilitates slow and controlled release of K, providing a sustained nutrient supply that aligns more closely with the temporal uptake pattern of wheat. Many studies have shown that biochar not only enhances extractable K but also reduces K fixation by modifying mineral–surface interactions and improving soil chemical stability, ultimately contributing to increase in wheat growth and yield (Biederman & Harpole, 2013). Despite these benefits, the effects of biochar application on K fixation, K release kinetics, and wheat productivity in acidic Alfisols remain insufficiently elucidated, particularly under field conditions in eastern India. The present study was conducted to evaluate the impact of rice straw biochar on the dynamics of soil-available potassium under acidic soil conditions in Jharkhand.

Materials and Methods

Experimental site

The study was conducted at ICAR-Indian Agricultural Research Institute, Gauria Karma, Hazaribagh, Jharkhand. The place is located at 24.2837°N latitude and 85.3528°E longitude, which falls within the Eastern Plateau and Hill Region (EPHR) and experiences a sub-humid tropical climate, receiving 1200–1400 mm of annual rainfall, mostly during the southwest monsoon (June–September).

Field experiment and treatment details

A wheat experiment was conducted with five rice straw biochar levels (0, 2.5, 5.0, 10.0, and 12.5 t ha^{-1}) in three replications during the Rabi season, 2024-25. The biochar was produced from locally available rice straw using a drum-type kiln under slow pyrolysis (350–450°C) in oxygen-limited conditions. Wheat variety, HD 3369, was sown manually in 20 cm rows at the rate of 100 kg ha^{-1}. The biochar was applied in the seed row along with a basal dose of fertilizer (50 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1} and 20 kg K_2O ha^{-1}), followed by sowing of the wheat seed. The full doses of biochar, P, K, and half of N were applied at the time of sowing. The remaining N was top-dressed in two equal doses (25 kg ha^{-1}) at 20 days after sowing (DAS) and at the active tillering stage. Standard irrigation, weed management, and plant protection practices were followed uniformly across treatments.

Soil sampling and analysis

Soil samples were collected from each treatment at key growth stages, i.e. before sowing, 7 days after sowing, 7 days after each nitrogen application, and after harvest. Soil samples were taken from the 0–15 cm depth using a stainless-steel auger. An initial composite sample was collected to determine baseline soil properties. During each sampling event, 15 samples were collected (5 treatments × 3 replications). Samples were placed in labelled polyethene bags and transported to the laboratory. In the lab, soil samples were air-dried, gently crushed, and passed through a 2 mm sieve for subsequent physical and chemical analysis. The sample was analyzed for physicochemical properties by standard protocols. The available soil potassium was analyzed by flame photometer after extraction with ammonium acetate.

Data analysis

All generated soil and biochar-related data were fed into an Excel sheet. The data were analyzed for mean and standard deviation. The mean data were compared using one-way ANOVA at a 95% level, followed by DMRT post hoc test.

Results and Discussion

Physico-chemical characteristics of rice straw biochar

The yield of biochar produced from rice straw by the local drum technique was about 49±4% of the total feedstock, i.e. rice straw fed to the kiln. The biochar and water suspension prepared at a 1:20 (w/v) ratio had a pH of 9.80 (± 0.01) and a comparatively high electrical conductivity (EC) of 5.30 (± 0.20 dS m^{-1}), indicating a strongly alkaline nature of the biochar with high soluble salt and mineral ash content. The rice straw biochar exhibited distinctly high potassium (K) content in both its available and total nutrient fractions. The concentration of available K was 6.4 ± 0.03 g kg^{-1}, indicating a substantial immediately soluble and plant-accessible K pool. Correspondingly, the total K content was 18.00 ± 1.20 g kg^{-1}, confirming a large inherent K reserve within the biochar matrix (Table 1). Table 1 presents the amount of potassium supplied to the soil via biochar across different application rates. The available K supplied by biochar ranged from 16.2 kg ha^{-1} at the lowest application rate (2.5 t ha^{-1}) to 80.8 kg ha^{-1} at the highest rate (12.5 t ha^{-1}). Similarly total amount of K supplied by biochar ranged from 45.0 kg ha^{-1} under the 2.5 t ha^{-1} treatment to 225.0 kg ha^{-1} at 12.5 t ha^{-1}. The combination of high available and total K content in rice straw biochar suggests that the applied biochar can act both as a rapid-release K source, i.e. immediately available to the crop, as well as a longer-term nutrient reservoir, i.e., slowly released nutrient pools, thereby contributing significantly to soil K enrichment and improving potassium nutrition in crop production systems (Lehmann & Joseph, 2015; Lawrinenko & Laird, 2015). Such dual nutrient release behaviour is particularly beneficial for nutrient-deficient, acidic Alfisols, where biochar can simultaneously improve short-term K availability and long-term K buffering (Ding *et al*., 2016). The high levels of available K content in rice straw biochar in this study are well-documented characteristics of rice-residue biochars, which typically contain large quantities of water-soluble and exchangeable K due to ash accumulation during pyrolysis (Singh *et al*., 2010; Wu *et al*., 2012). The strong alkalinity (pH 9.8) and elevated EC of the biochar further promote rapid dissolution of K into the soil solution, explaining the higher available K contributions under increasing biochar doses (Yuan *et al*., 2011).

Impact of biochar on the dynamics of available soil Potassium

The results showed that biochar had a highly significant effect on available soil potassium (K) throughout the crop growth period ($p < 0.01$) (Table 2). Soil samples collected at 7, 37, 66, and 121 days after basal fertilizer application revealed a consistent increase in available K over time across all treatments (Fig. 1). Biochar application markedly enhanced soil K at every stage, and higher biochar doses resulted in greater K availability. At early growth (7 DAS), available K rose from 106.3 kg ha^{-1} in the control (B0) to 169.9 kg ha^{-1} in the treatment with the highest biochar dose (B12.5), representing a 59.7% increase. This trend increases as the crop growth progressed. At 37 DAS, B12.5 recorded 57.9% higher K (231.8 kg K ha^{-1}) than the control (146.8 kg K ha^{-1}). Mid-season (66 DAS) values showed a similar pattern, with available K ranging from 173.3 kg ha^{-1} in B0 to 268.9 kg ha^{-1} in B12.5 (+55.2%). By harvest (121 DAS), K availability remained highest in the biochar-amended treatments, with B12.5 reaching 297.0 kg ha^{-1}, an increase of 55.7% over the control (190.7 kg ha^{-1}).

Table 1. Quantity of potassium supplied by Biochar under various treatments

K content in biochar		Quantity of potassium supplied by biochar (kg ha^{-1})			
		B1 (2.5 t ha^{-1})	B2 (2.5 t ha^{-1})	B3 (2.5 t ha^{-1})	B4 (2.5 t ha^{-1})
Available K	6.4 g kg^{-1}	16.2	32.3	64.6	80.8
Total K	18.00 g kg^{-1}	45.0	90.0	180.0	225.0

Table 2. Quantity of available soil potassium at various stages of crop growth

Treatment	7 DAS (kg K ha^{-1})	37 DAS (kg K ha^{-1})	66 DAS (kg K ha^{-1})	121 DAS (kg K ha^{-1})
B0	106.3a	146.8a	173.3a	190.7a
B2.5	128.8b	168.2a	196.3b	209.3a
B5	165.4c	203.6b	238.5c	258.2b
B10	162.6c	227.3b	252.6d	268.9b
B12.5	169.9c	231.8b	268.9e	297.0b

Note: As per the DMRT test, the mean values within a column having the same alphabet are not significantly different at the 95% level.

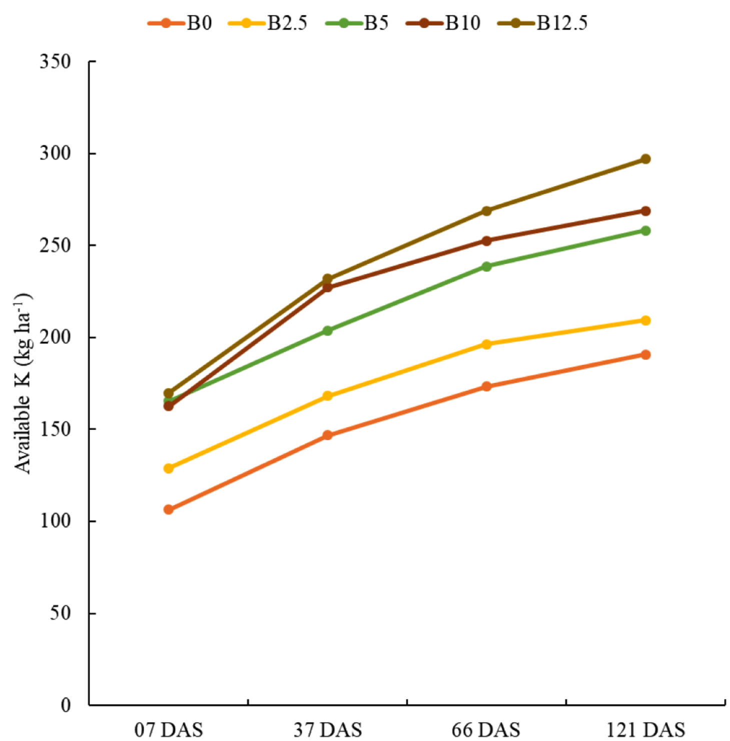

Fig. 1. Temporal variation in available soil-K content among the biochar treatments

The biochar-treated soil had a significantly higher amount of available soil-K compared to non-biochar-treated plots. This might be attributed to the high available and total K content in biochar. It was reported that, due to the high intrinsic K content of rice straw biochar and its gradual release during mineral weathering, K availability in soil is generally enhanced (Zörb *et al*., 2014). Enhanced cation exchange capacity from biochar application further supports K retention and minimizes leaching losses (Hossain *et al*., 2020). Sustained K availability in biochar-treated acidic soils has been similarly observed in long-term field trials (Premalatha *et al*., 2023). Overall, the results confirm earlier findings that cereal-residue biochars significantly enhance soil potassium status and can reduce dependence on external K fertilizers (Jeffery *et al*., 2017; Glaser & Lehr, 2015).

Conclusion

Rice straw biochar significantly improved soil potassium availability and wheat performance in acidic Alfisols. Higher biochar rates (10–12.5 t ha^{-1}) consistently enhanced both available and total soil K throughout the crop cycle. The effect is attributed to biochar's high intrinsic K content, gradual nutrient release, and improved cation exchange capacity, which reduces K fixation and sustains nutrient availability. These results indicate that integrating rice straw biochar with nitrogen fertilization is an effective strategy to enhance soil fertility, optimize K nutrition, and increase wheat productivity in nutrient-depleted acidic soils.

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Received: 13 March 2025; Accepted: 29 May 2025